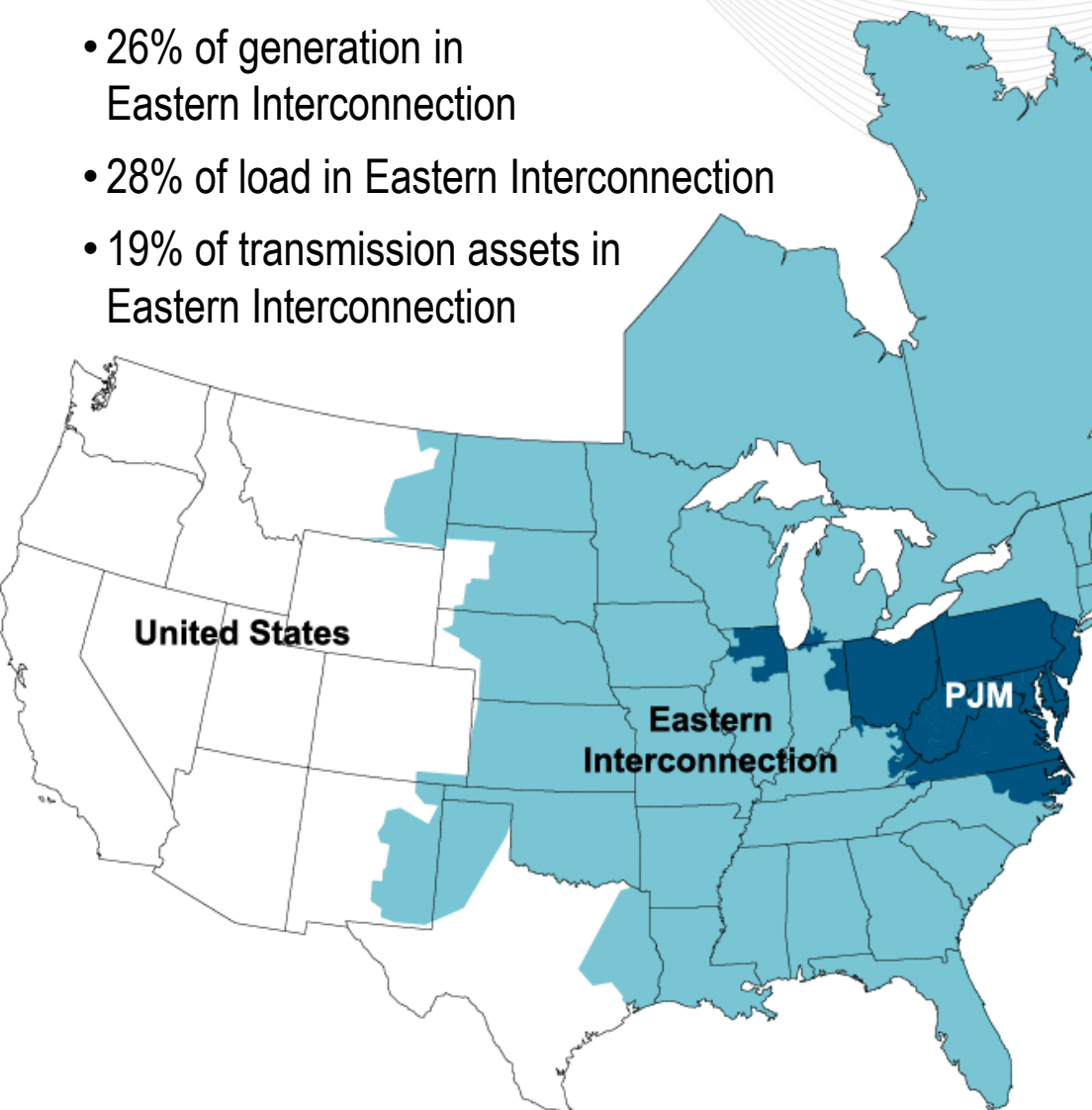


PJM Renewable Integration Challenges

Solar Power International Post-Conference Workshop
September 14, 2012

Ken Schuyler
Renewable Services
PJM Interconnection

- 26% of generation in Eastern Interconnection
- 28% of load in Eastern Interconnection
- 19% of transmission assets in Eastern Interconnection



KEY STATISTICS

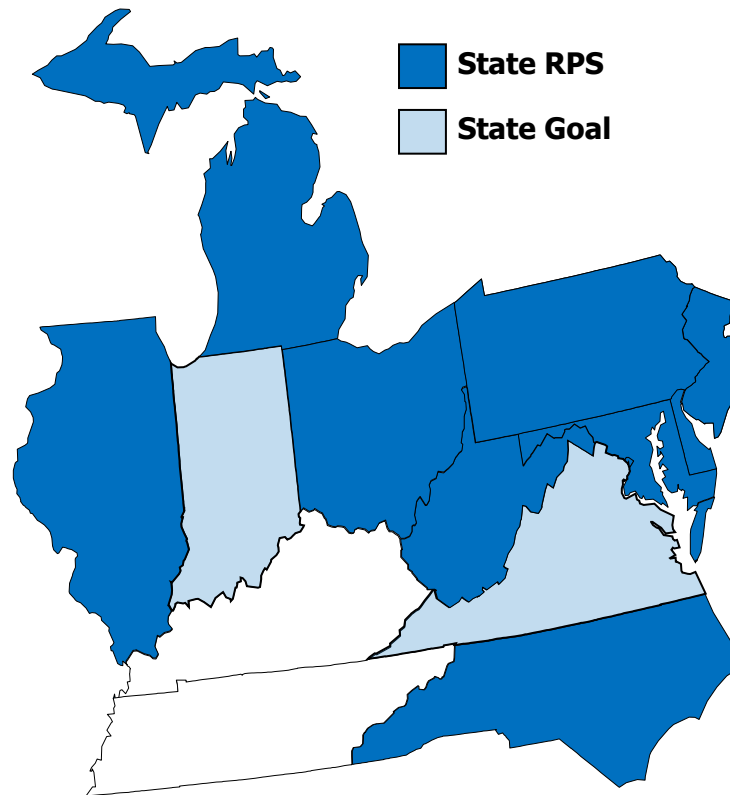
PJM member companies	750+
millions of people served	60
peak load in megawatts	163,848
MW of generating capacity	185,600
miles of transmission lines	65,441
GWh of annual energy	832,331
generation sources	1,365
square miles of territory	214,000
area served	13 states + DC
Internal/external tie lines	142

**21% of U.S. GDP
produced in PJM**

As of 1/4/2012

State Renewable Portfolio Standards (RPS) require suppliers to utilize wind and other renewable resources to serve an increasing percentage of total demand.

State RPS Targets:



- ☀ NJ: 22.5% by 2021
- ☀ MD: 20% by 2022
- ☀ DE: 25% by 2026
- ☀ DC: 20% by 2020
- ☀ PA: 18%** by 2020
- ☀ IL: 25% by 2025
- ☀ OH: 25%** by 2025
- ☀ NC: 12.5% by 2021 (IOUs)
- WV: 25%** by 2025
- MI: 10% + 1,100 MW by 2015
- VA: 15% by 2025
- IN: 10% by 2025

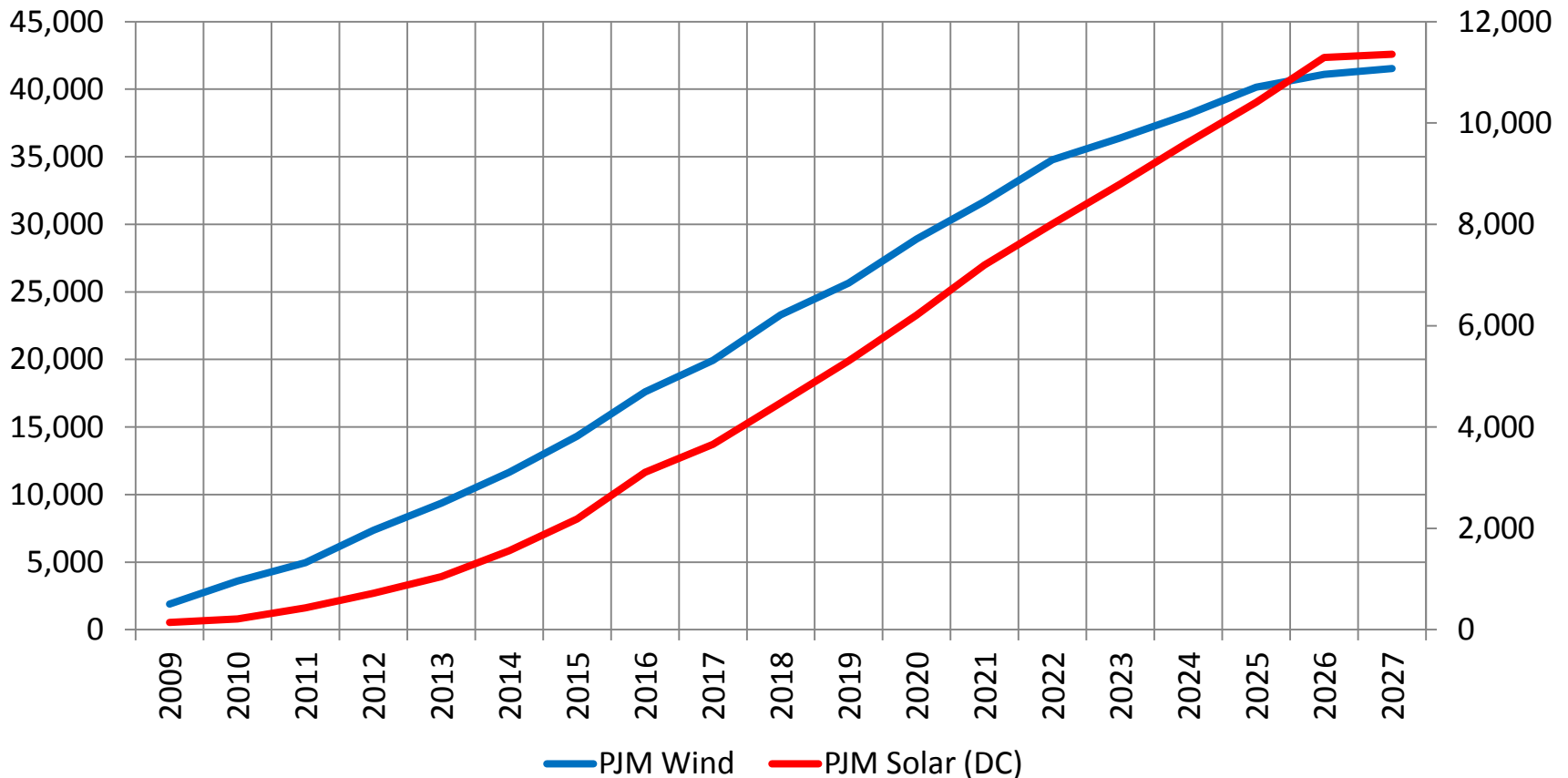
☀ Minimum solar requirement

** Includes separate tier of “alternative” energy resources

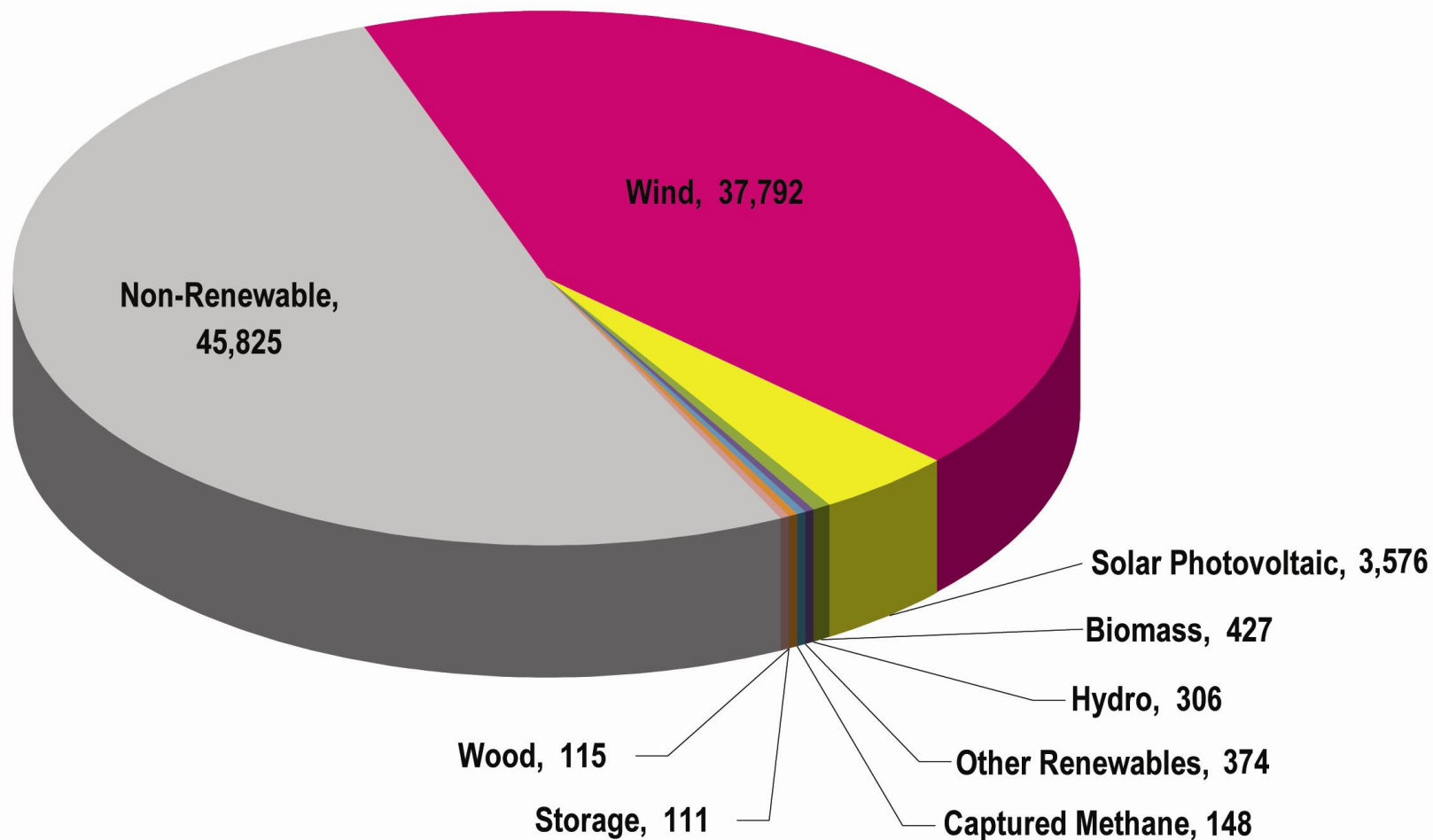
Projected Renewable Energy Requirements in PJM

By 2026: 133,000 GWh of renewable energy, 13.5% of PJM annual net energy
(41 GW of wind and 11 GW of solar)

Wind and **Solar** Requirements in PJM (MW)

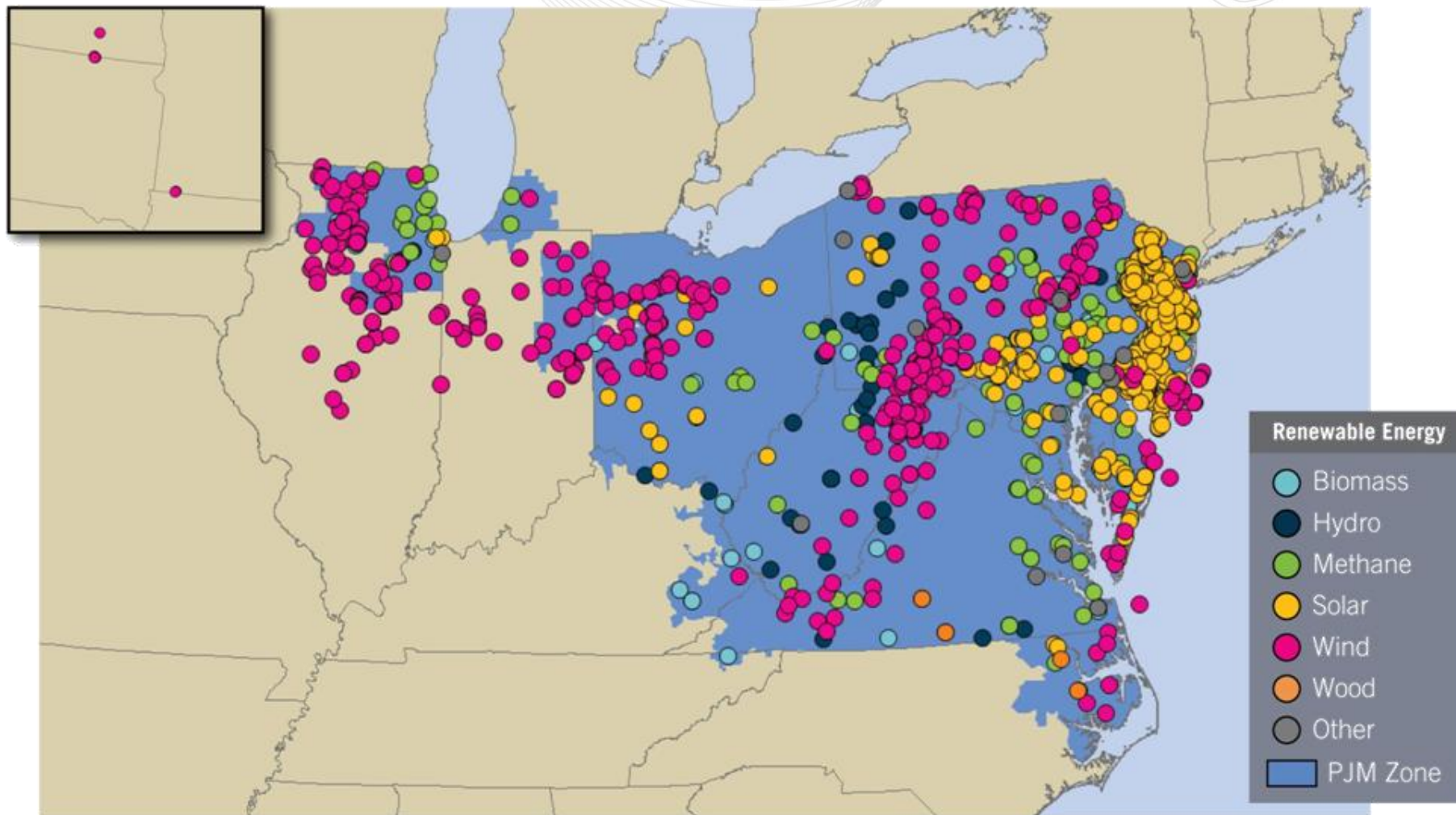


Proposed Generation (MW) in PJM



As of January 4, 2012

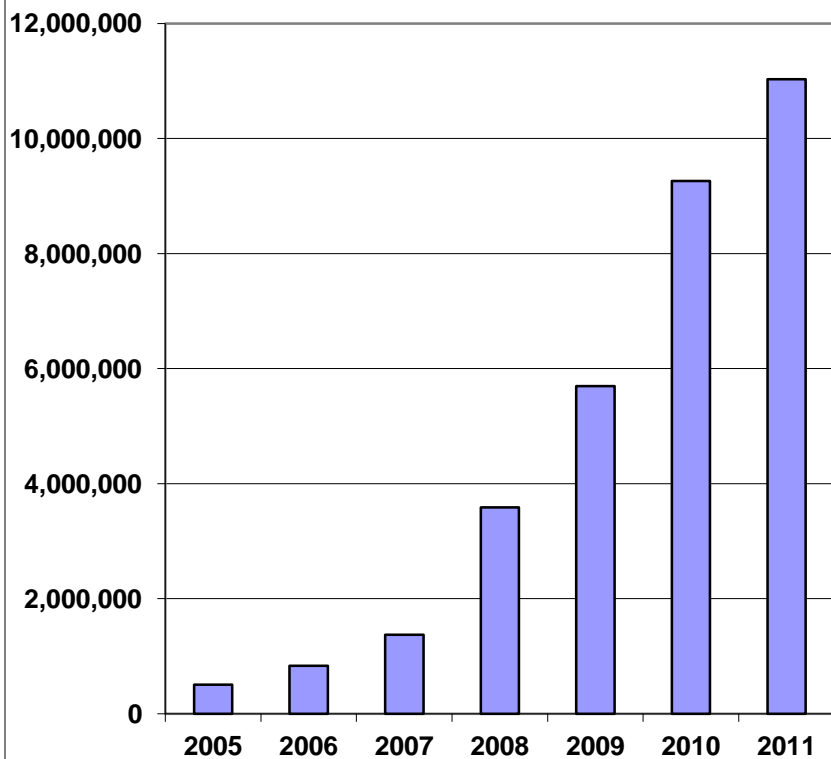
Proposed Renewable Generation in PJM



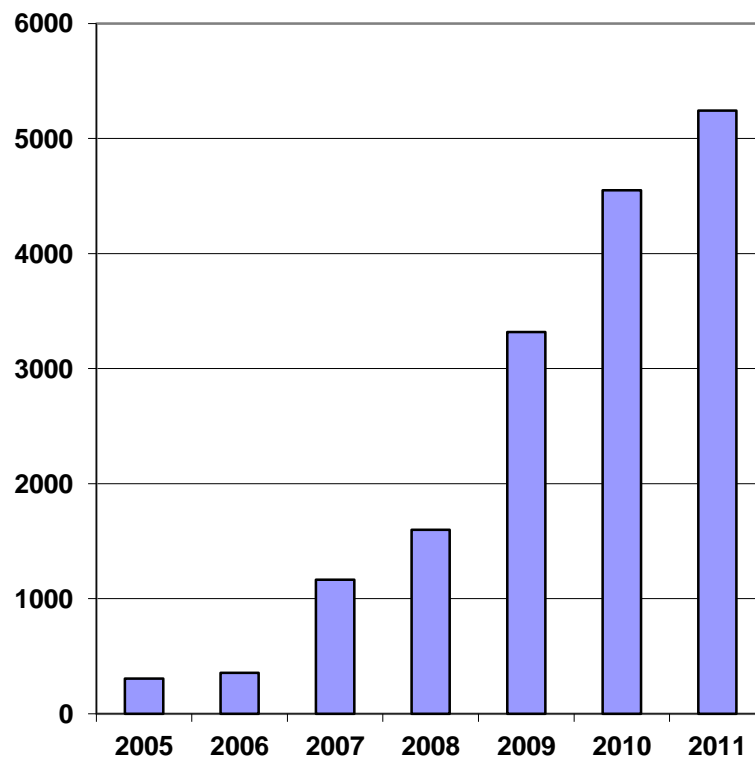
As of January 4, 2012

Increasing Wind Penetration in PJM

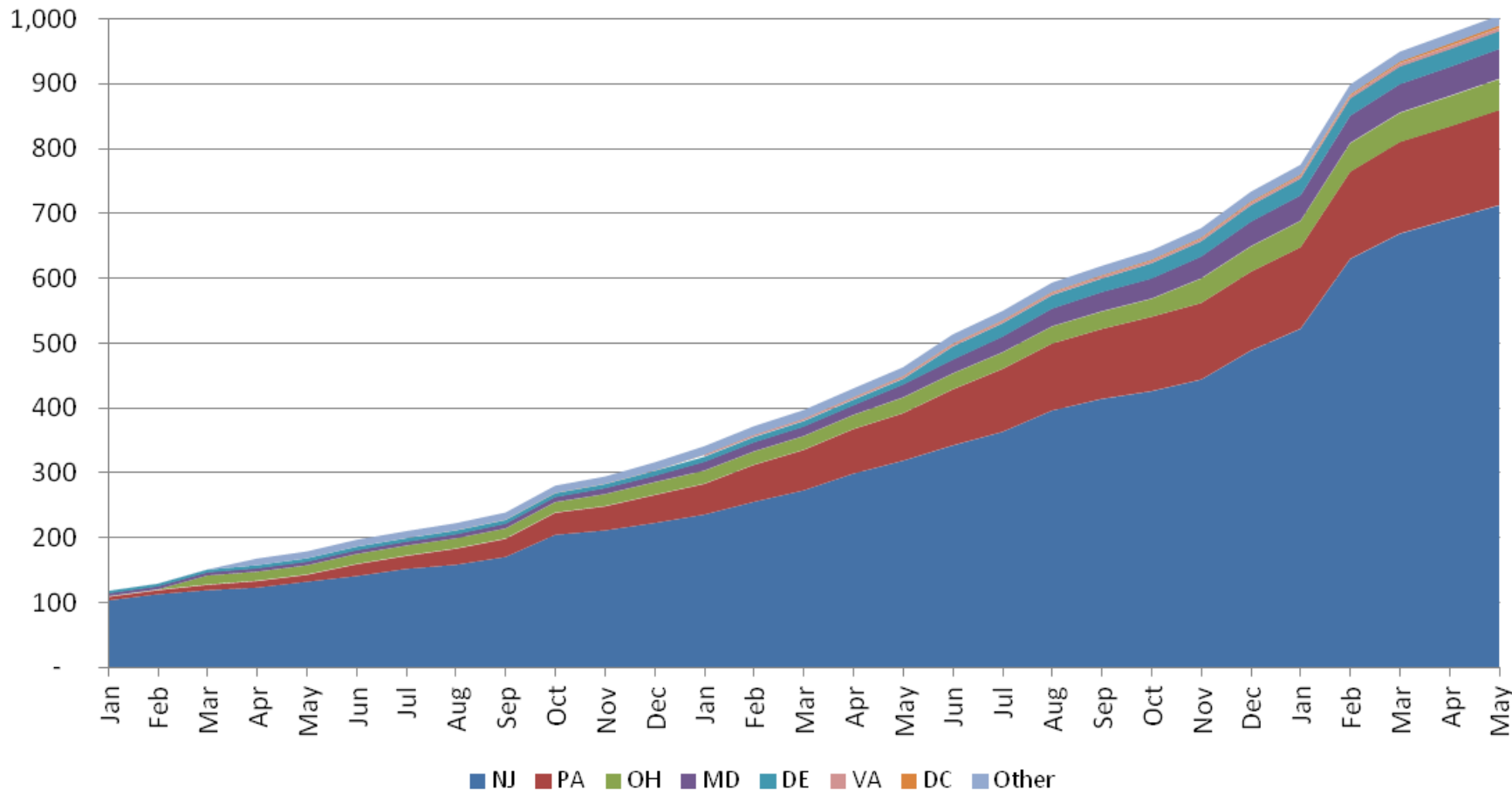
PJM Wind Energy (MWh)



PJM Wind Nameplate Capability (MW)

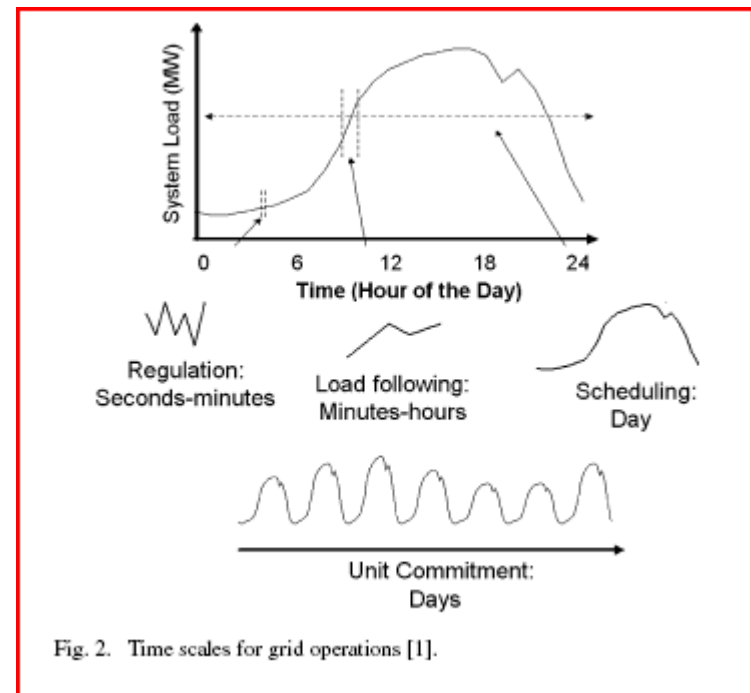


Installed Solar PV (MW_{DC}) (1/2010 to 5/2012)



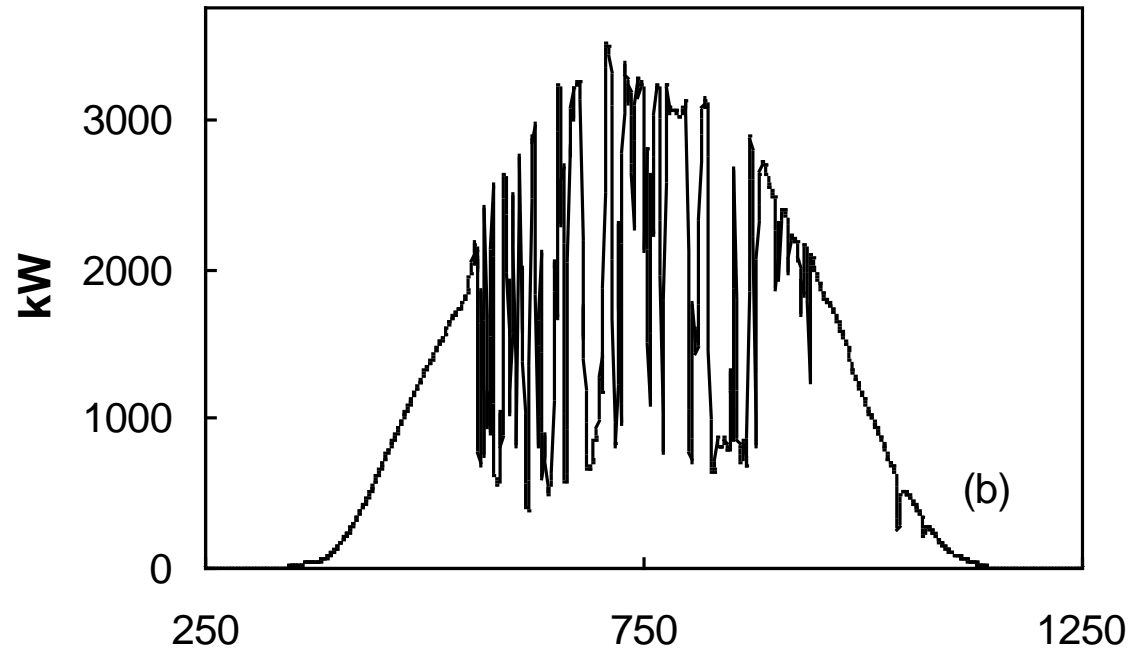
Increasing **variability** and **uncertainty**:

- **Minute-to-Minute**
 - Additional generation needed to provide regulation
- **Intra-Hour**
 - Conventional generators must adjust output
- **Day Ahead**
 - Forecast errors cause over- or under-scheduling



Variability of Solar PV

4.6 MW TEP Solar Array (Arizona)

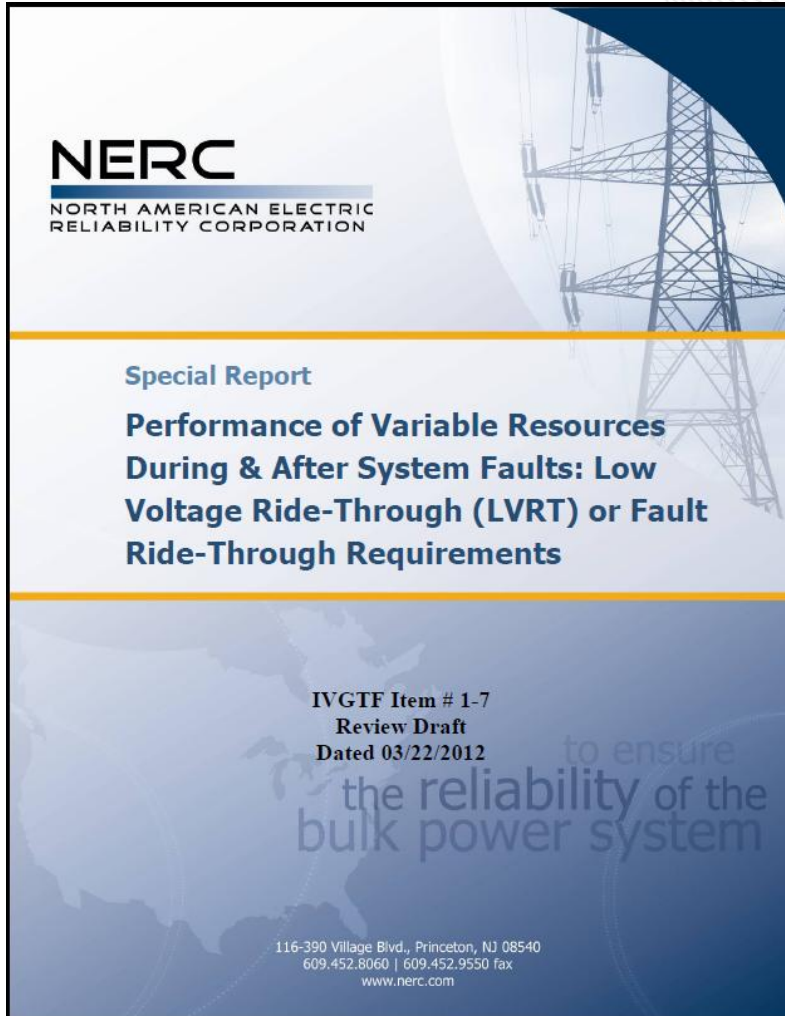


Source: Carnegie Mellon University

Impact of Increasing Renewable Penetration

ISOs and RTOs reduce costs associated with variability and uncertainty:

Characteristic	Impact to Renewable Integration Cost
Larger balancing areas	<ul style="list-style-type: none">• Reduces overall increase in variability• Less regulation and ramping service required
Faster markets, i.e., shorter scheduling intervals (5-15 minutes)	<ul style="list-style-type: none">• Less regulation required to accommodate intra-hour variations
Larger geographic area	<ul style="list-style-type: none">• Increases wind and solar diversity and reduces overall variability
Centralized wind and solar power forecasting	<ul style="list-style-type: none">• Cost-effective approach to reduce scheduling impacts
Regional / Interregional Transmission Planning	<ul style="list-style-type: none">• Cost-effective upgrades to ensure grid reliability and mitigate congestion



NERC IVGTF – Task 1-7

“Performance of Variable Resources During & After System Faults:

Low Voltage Ride-Through (LVRT) or Fault Ride-Through Requirements”

FERC Order 661A

Low Voltage Ride-Through

- **Generator must remain in service (with close to pre-disturbance output) following:**
 - Normally cleared 3-phase faults to a max. 9 cycles (TOP to provide clearing time)
 - 1-phase faults with delayed clearing
 - TOP provided post-fault voltage recovery

(Must not TRIP Requirement)

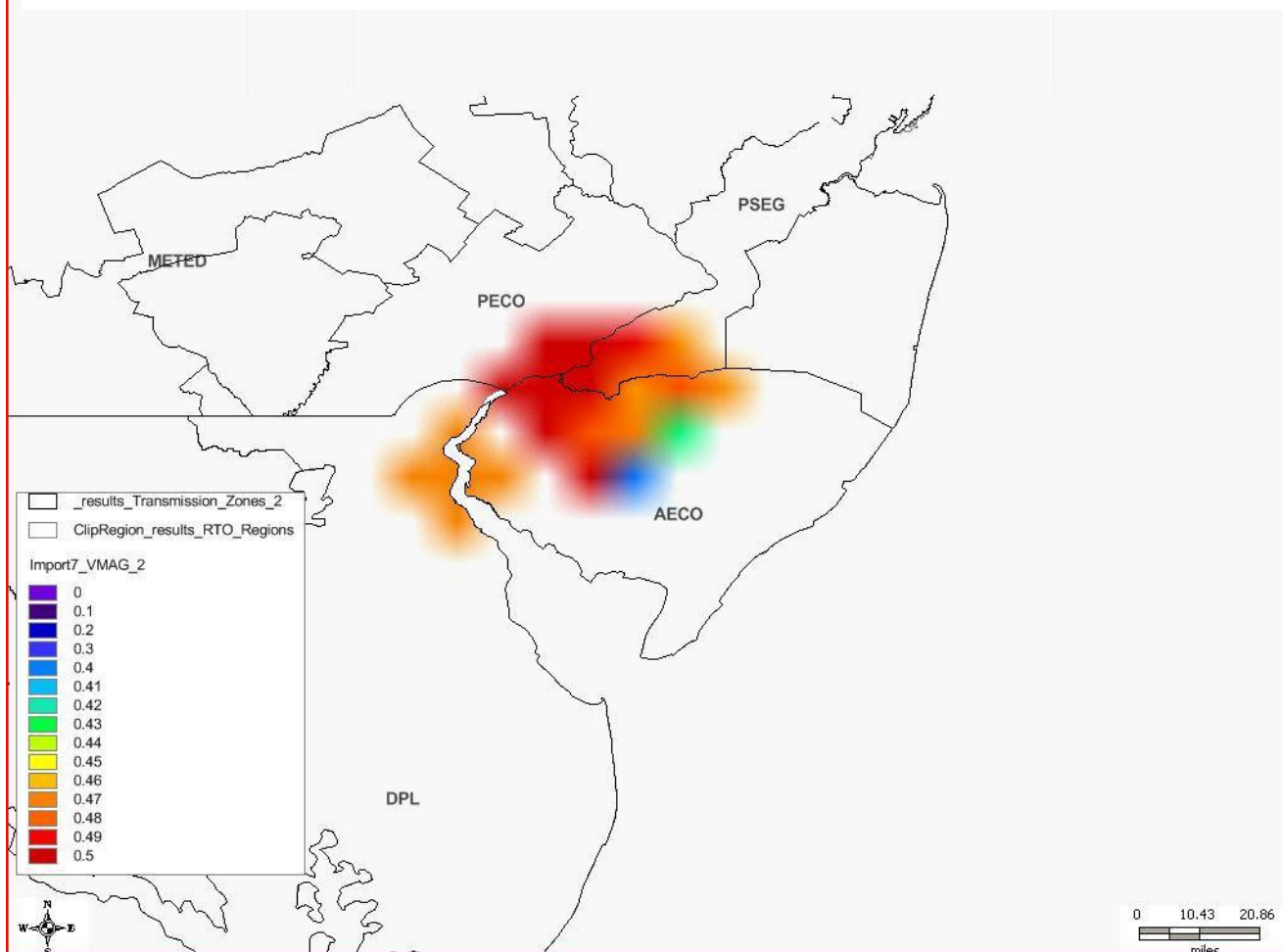
IEEE Standard 1547

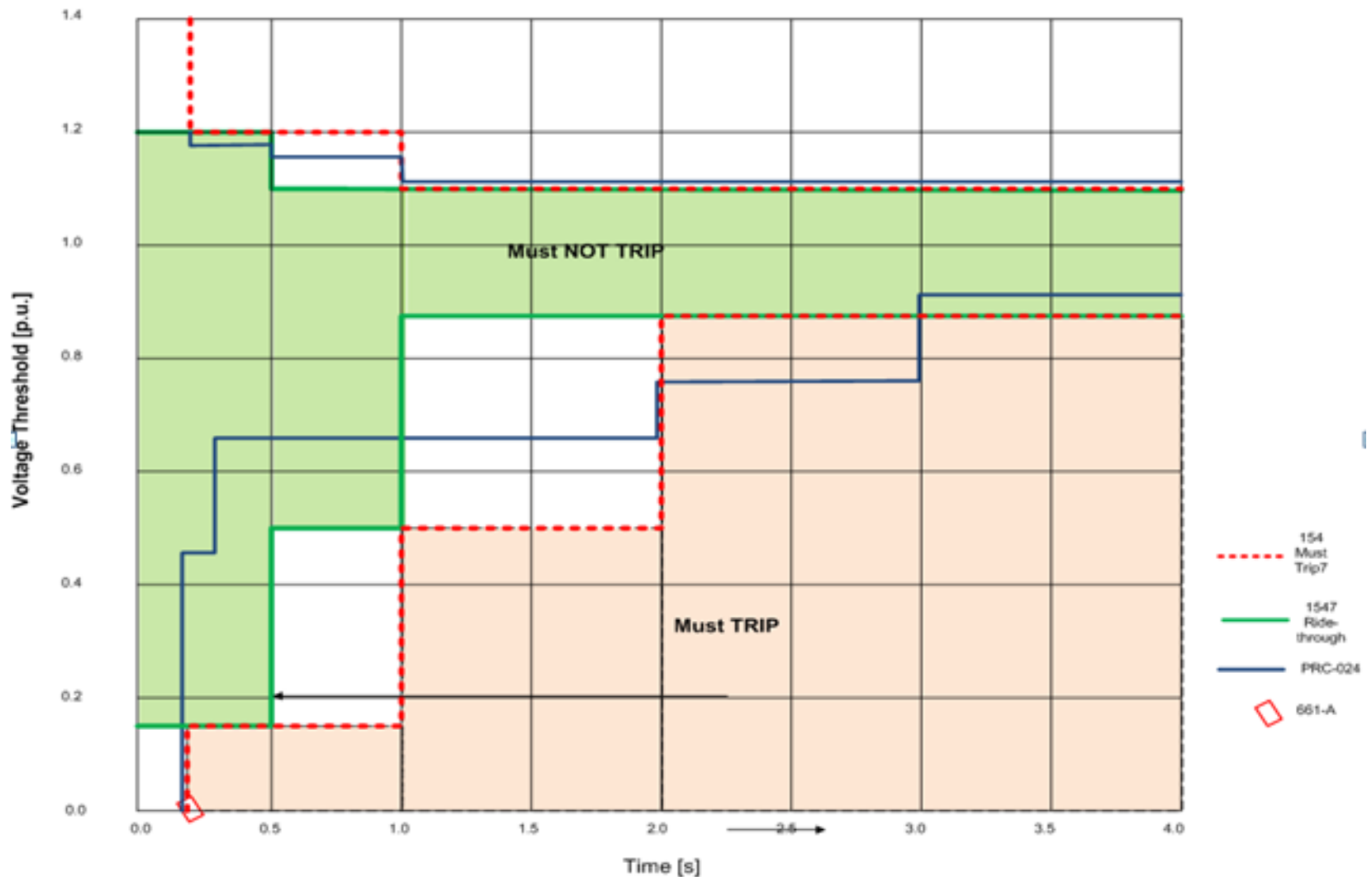
Anti-islanding Requirements

Voltage Range (% of base voltage)	Clearing time(s)
$V < 50$	0.16
$50 \leq V < 88$	2.00
$110 < V < 120$	1.00
$V \geq 120$	0.16

(Must TRIP Requirement)

Voltages below 0.5 P. U. for a 500 kV fault





- **Intermittent Resource Task Force (IRTF)**
 - Stakeholder group to address market, operational, and reliability issues specific to variable resources.
- **Energy Markets / Operations**
 - Implemented a centralized wind power forecast service.
 - Implemented changes to improve wind resource dispatch / control.
 - Demand Response / Price Responsive Demand improves operational flexibility
- **Ancillary Service Markets**
 - Implemented tariff changes to allow Energy Storage Resources to participate in PJM ancillary services markets
 - Frequency Regulation - new methodology to compensate better performing resources (like storage), per FERC Order No. 755
 - Reduced minimum size for participating resources from 1MW to 100kW.

- **Transmission Planning**

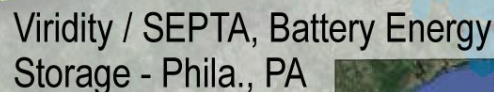
- Light load criteria implemented to improve grid reliability
- Expansion planning considers public policy impacts (i.e., RPS)
- Grid interconnection requirements for wind and solar being evaluated

- **Evaluating Potential Grid Impacts**

- Initiated a PJM Renewable Integration Study (PRIS) to assess impacts to planning, markets, and operations

- **Advanced Technology Research Program**

- Pilot programs are underway across the PJM footprint to evaluate new technologies and remove barriers to participation in PJM markets and operations.



- Solar + Storage = “FirmPV”
- **Purpose:** Evaluate costs, benefits, and operating characteristics of coupling distributed, behind-the-meter solar PV with battery storage
 - Battery system being supported by California PUC grant award
- 9.4 kW PV ground mounted array (SolarCity)
- 18 kWh Li-ion battery (Tesla Motors)
- 20-yr Power Purchase Agreement



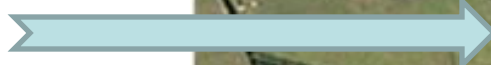


(9.4 kW array)

PV Array



Battery and inverters



- Flexible resources will be needed to offset the impacts of variable generating resources
- New market players:
 - Price Responsive Demand
 - Smart Grid Technologies
 - Energy Storage Resources
 - battery arrays
 - flywheels
 - compressed air energy storage
 - plug-in hybrid electric vehicles (PHEVs)
- Grid Interconnection Standards will need to be updated to ensure reliability with greater market penetrations

- For more information about PJM's initiatives:
 - Exploring Tomorrow's Grid: New developments and technologies to advance the grid:
<http://pjm.com/about-pjm/exploring-tomorrows-grid/smart-grid.aspx>
 - Renewable Energy Dashboard: See how PJM is working to bring renewable energy to the grid:
<http://pjm.com/about-pjm/renewable-dashboard.aspx>